

**EFFECT OF FIBER LASER MODIFICATION ON SURFACE MARKING OF  
22MnBr5 BORON STEEL**

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**in fulfilment of the requirements for the degree of Master of Manufacturing  
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## DECLARATION

I declare that this thesis entitled “Effect of Fiber Laser Modification on Surface Marking of 22MnBr5 Boron Steel” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : .....

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## **APPROVAL**

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Manufacturing Engineering (Advanced Materials and Processing).

Signature : .....

Supervisor Name : .....

Date : .....

## **DEDICATION**

Only

my beloved father, Mohd Nor Bin Musa

my loving mother, Che Esah Binti Mamat

my friends

for giving me moral support, money, cooperation, encouragement and understandings

Thank You So Much!

## ABSTRACT

Laser engraving is a method in which a laser fiber is bombarded into the material surface. This research is conducted to evaluate the effect of engraving speed, laser power and frequency on the 22MnBr5 Boron steel based on the surface roughness and hardness. Furthermore, the purpose of this research also to propose optimum laser parameters of 22MnBr5 Boron steel based on the surface roughness and hardness. The variable parameters which are laser power, engraving speed and laser frequency were designed using experiment design (DOE). The specimen been tested is 22MnBr5 boron steel. The sample is engraved based on the parameters extracted from the DOE. The engraved parts are analyzed in terms of surface integrity (surface roughness) and its hardness. The surface roughness is measured using a surface roughness tester whereas the Rockwell hardness tester is utilized to measure the hardness value of each engraved sample. From the response that is obtained from the experiment, the ANOVA analysis is done to identify the effect of the variable parameters on the surface roughness and hardness value. Based on the analysis, it can be concluded that all the parameters; engraving speed, laser power and frequency are significant and the range of value used are valid on the surface roughness and hardness testing. This experiment reveals that the higher the engraving speed, the smoother the surface of the engraved part. The smoothest value of surface roughness is 1.65 $\mu$ m value from the highest engraving speed of 4000mm/s. In addition, the analysis from RSM shows that the relationship between the parameters and the surface roughness is quadratic. Meanwhile, the linear relationship is achieved between the parameters and the hardness value. The highest hardness value of 39.91 HRC is obtained from the engraving speed of 4000mm/s. This means that the frequency did not establish major variations on the distribution of the hardness. Thus, the situation reveals that the engraving frequency parameter is the least significant compared to the engraving speed and laser power parameters.

## ABSTRAK

*Ukiran laser adalah kaedah di mana serat laser diujikan ke permukaan bahan. Penyelidikan ini dilakukan untuk menilai kesan kelajuan ukiran, daya laser dan frekuensi pada keluli Boron 22MnBr5 berdasarkan kekasaran permukaan dan kekerasan. Selanjutnya, tujuan penyelidikan ini juga untuk mencadangkan parameter laser optimum keluli Boron 22MnBr5 berdasarkan kekasaran permukaan dan kekerasan. Parameter berubah-ubah iaitu daya laser, kelajuan ukiran dan frekuensi laser dirancang menggunakan reka bentuk eksperimen (DOE). Spesimen yang diuji adalah keluli boron 22MnBr5. Sampel terukir berdasarkan parameter yang diekstrak dari JAS. Bahagian yang terukir dianalisis dari segi integriti permukaan (kekasaran permukaan) dan kekerasannya. Kekasaran permukaan diukur menggunakan penguji kekasaran permukaan sedangkan penguji kekerasan Rockwell digunakan untuk mengukur nilai kekerasan setiap sampel yang terukir. Dari tindak balas yang diperolehi dari eksperimen, analisis ANOVA dilakukan untuk mengenal pasti pengaruh parameter pemboleh ubah pada kekasaran permukaan dan nilai kekerasan. Berdasarkan analisis, dapat disimpulkan bahawa semua parameter; kelajuan ukiran, daya laser dan frekuensi adalah signifikan dan julat nilai yang digunakan adalah sah pada ujian kekasaran dan kekerasan permukaan. Eksperimen ini mendedahkan bahawa semakin tinggi kelajuan ukiran, semakin halus permukaan bahagian yang terukir. Nilai kekasaran permukaan yang paling halus adalah nilai  $1.65\mu\text{m}$  dari kelajuan ukiran tertinggi  $4000\text{mm/s}$ . Di samping itu, analisis dari RSM menunjukkan bahawa hubungan antara parameter dan kekasaran permukaan adalah kuadratik. Sementara itu, hubungan linear dicapai antara parameter dan nilai kekerasan. Nilai kekerasan tertinggi  $39.91\text{ HRC}$  diperolehi daripada kelajuan ukiran  $4000\text{mm/s}$ . Ini bermaksud bahawa frekuensi tidak menunjukkan variasi utama pada taburan kekerasan. Oleh itu, keadaan menunjukkan bahawa parameter frekuensi ukiran adalah yang paling tidak signifikan dibandingkan dengan parameter kelajuan ukiran dan daya laser.*

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## LIST OF ABBREVIATION

2D	–	2-dimension
3D	–	3-dimension
ANOVA	–	Analysis of Variance
CO <sub>2</sub>	–	Carbon Dioxide
DOE	–	Design of Experiment
EDM	–	Electrical Discharge Machining
FKP	–	Fakulti Kejuruteraan Pembuatan
HSLA	–	High Strength Low Alloy
LBM	–	Laser Beam Machining
MPa	–	Mega Pascal
Nd:YAG	–	Neodymium-doped Yttrium Aluminium Garnet
RSM	–	Response Surface Method
UTeM	–	Universiti Teknikal Malaysia Melaka
UTS	–	Ultimate Tensile Strength

## LIST OF SYMBOLS

°	-	degree
µm	-	micrometer

# **CHAPTER 1**

## **INTRODUCTION**

### **1.1 Background**

Laser which is stand for Light Amplified Stimulated Emission Radiation is a source of monochromatic, coherent and unidirectional light, in contrast to a standard light beam. Lasers are implemented widely across multiple applications in everyday life: CD and DVD, bar code scanners, entertainment, welding or cutting in industry, fire control aid, or road and tunnel alignment (Legres et al., 2014).

The basic concept of laser technology is the emission of photons generated by external energy sources stimulating the atoms. Because of this excitation, the electrons can change their orbit, and the return to their initial state is completed as in form of photons with the emission of energy (Geavlete et al., 2016). The processing of materials is one of the leading laser applications in which lasers cut, drill, weld, heat-treat and otherwise affect both metals and non-metals. Lasers can drill tiny holes faster and more expensively in turbine blades than mechanical drills. Lasers had many benefits over traditional cutting materials techniques. Lasers do cuts with greater edge efficiency, for example, than most mechanical cutters. Rarely need to file or polish the edges of metal parts cut by lasers, because the laser helps make such a clean cut (Codemard et al., 2016). Laser machining

provides a viable production method for hard-to-machine materials and special applications such as micromachining, while compared with traditional machining method, it has limitations in terms of material removal rate and surface quality.

Laser technologies are a part of progressive material treatment methods. Both approaches deal with the processing of work-piece material on solid (or liquid or diode) base with a high-energy laser beam. Laser marking systems involving varying lasers and optical delivery systems as metals, plastics, ceramics, glass, wood and leather as well as painted surfaces and photographic emulsions can be used to mark an almost endless list of materials. Components or product marking methods are various, including marks, ink systems, mechanical engraving, and embossing, chemical and dry etching. Each has its own use, but the laser marking is becoming increasingly popular. The use of laser metal engraving is shown in the Figure1.1, where we can compare it to other part production marking systems (Fedorycheva et al., 2015).

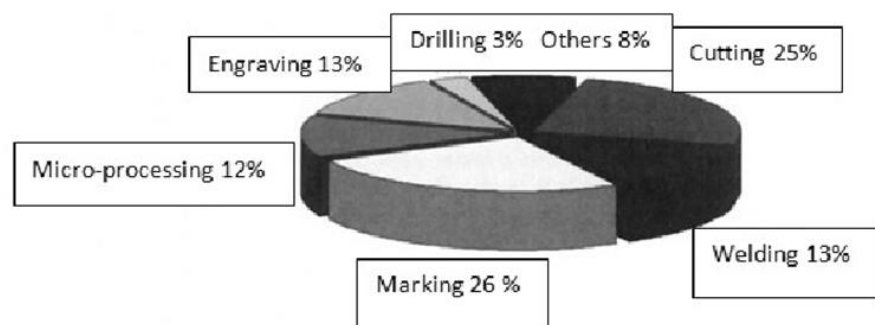


Figure 1.1: Percentage of laser used technologies (Fedorycheva et al., 2015).

A fibre laser is a laser in which the medium of active gain is an optical fibre doped with rare earth elements such as erbium, ytterbium, neodymium, dysprosium, praseodymium and thulium. The FL is a fibre laser converter to all results since it transforms the coherent wavelength(s) of the laser pump to different (also coherent)



wavelength(s). Light is already attached to a versatile fibre, so the reality that the light is already in a fibre enables it to be conveniently transmitted to a movable focusing point. This is also essential for the laser cutting, welding and folding of metals and polymers. Fiber lasers can have active regions that are several kilometres long and can thus have a very high optical gain. Because of the high surface area of the fibre to volume ratio, they can accommodate kilowatt amounts of continuous processing power, which makes for effective cooling. This can prevent the heating to occur that might change the properties of materials throughout the processes. This means that when supplying up to certain watts, these devices don't need cooling systems. These special features make them among the best candidates to develop new laser sources (Giuseppe and Devices, 2015).

In addition, the material used in this experiment is Boron steels which widely used as a wear tool and as high strength structural steel for a wide range of applications. An expanding area of Boron use is the low alloy (HSLA) high-resistance field and other structural steels. It can be supplied either as hot rolled or as quenched and tempered (the latter are more typical for Boron grades). Boron ensures adequate hardness in heavier sections of plates. Furthermore, the advantages of Boron steel are; enhanced cold formability, lower delivered hardness resulting in better blanking tool life, improved weldability due to low carbon equivalents, lower tempering temperatures leading to energy savings, and good in hardening response.

## **1.2 Problem Statement**

By focusing energy directly on the surface to be marked, laser etching markers run. The heat produced by the beam actually alterations the part's surface or vaporises the

substance on the surface. In other metals (other than steel), as material is removed by high temperature vaporisation, the surface is engraved. It modifies the metal alloy and etches the surface in a way that degrades the strength of the component and can lead to failure of fatigue or stress corrosion cracking. So, the use of fiber laser engraving machine is utilized in this research.

### **1.3 Objectives**

The purposes of this project investigation are to;

- To evaluate the effect of engraving speed, laser power and frequency on the 22MnBr5 Boron steel based on the surface roughness and hardness.
- To propose optimum laser parameters of 22MnBr5 Boron steel based on the surface roughness and hardness.

### **1.4 Scope**

The main purpose of the project is to study the effect of fiber laser modification on surface marking of 22BrMn5 Boron steel. This research will be performed in Universiti Teknikal Malaysia Melaka (UTeM) with the usage of laser fiber engraving machine due to its high output power, fast marking speeds, high optical quality and better marking edges. The use of laser engraving machine will be done with the different parameters such as laser power, engraving speed and frequency. The specimen being tested would be 22MnBr5 boron steel.

The engraved parts were analysed in terms of roughness of the surface roughness and hardness testing. The surface roughness is measured using a surface roughness tester

whereas the Rockwell hardness machine is used to measure hardness value. The most impactful parameter influence the results will also be analysed through variance analysis (ANOVA), which will accumulate the data using software developed by Design Expert.

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Introduction**

In this chapter, the literature review in very details and easy to understand is explained. The sources of the literature review are mainly from pervious related journal, article, website and many others. The content of the literature review includes the understanding of the material used in the current project, the explanation on how the laser engraving process take parts, the possible effect on the surface of the materials and the method used to achieve the optimal parameter of the project done.

#### **2.2 Boron Steel**

The material which will be used for this research is the Boron steel specimen. The code is 22MnB5 for this material. It is a high strength steel material made of alloy. According to (Gracia-Escosa et al., 2017), boron steel is usually used during hot stamping. This is due to its strong mechanical properties that make them ideal for use as a material for cutting tools. However, the Boron steel is most famous application is in the automotive industry. They are most suitable for producing car parts such as lightweight steel chassis.

This type of boron steel contains low boron addition to increase its properties. Some of the enhanced properties are high hardness, which means that the material can be raised to a high level. Next, the materials mechanical properties also get improved and the most significant change is that the 22MnB5 boron steel saves up to 50% in weight compared to conventional steel. In a standard hot stamping process, the tensile strength increased from 600MPa to 1500MPa at 950 ° C, cycle length 5 minutes and quenched in closed water-cooled die (Gracia-Escosa et al., 2017).

The boron steel is also one of the materials that can achieve a state of ultra-high resistance steels (UHSS) by undergoing laser cutting or cold blanking. However, both processes require a high cost, time consuming, and high blanking force. Hence, a few alternative processes were proposed which is the process of warm blanking and hot forming. Only the steps to achieve UHSS can be reduced by using the alternative method. The process's disadvantages, however, involve several form or dimension of blanking. The required punch dimensions, for example, are plane, conical, and truncated conical (Neumayer et al., 2019).

Some of the boron coated with Al that will cause the sheet surface adhered to the hot stamping surface to die when the cycle is complete. It is a situation which can alter the die shape, surface roughness and die coefficient of friction. The next product which undergoes hot stamping with the same die will be affected if this situation occurs. New lubricants have been developed to prevent this from happening.

(Fan et al., 2010) stated that research with boron steel undergoes an isothermal deformation range of 600°C to 800°C to observe the material's microstructure and mechanical properties. Throughout this condition the temperature of plastic strain and

deformation will be proven to affect the microstructure of the material and the mechanical properties.

As the result of research project, Ultimate tensile strength increase (UTS) might well be detected significantly. It is due to the refinement of the material's microstructure, and the same change also happens at 750 ° C. As a result the material's hardness and UTS increase due to the refinement of the microstructure. However, if the proportion of ferrite increases the hardness, and the UTS decreases.(Fan et al., 2010)

The analysis was conducted through practical testing and computational modelling for the formability of the boron steel surface. According (Chakraborty et al., 2019) stated that the sheet formability assessment can be calculated after deformation has occurred. They have done numerical modelling for the same formability properties. They claimed that the maximum degree of formability is as relative to certain processes, the substance is in its pure austenite process. Table 2.1 shows the composition of 22MnBr5 boron steel.

Table 2.1: Composition of 22MnBr5 boron steel (Tahir and Aqida, 2017)

<b>Chemical Element</b>	<b>Percentage (%)</b>
Carbon, C	0.250
Silicon, Si	0.400
Manganese, Mn	1.350
Phosphorus, P	0.023
Sulphur, S	0.010
Aluminium, Al	0.080
Nitrogen, N	0.010
Chromium, Cr	0.250
Boron, B	0.004

## **2.3 Laser**

Laser is an acronym for Light Amplification by Stimulated Radiation Emission. For light emission there are three main steps; they are absorption, Spontaneous Emission & Stimulated Emission. Laser has been extensively used in welding & cutting operations over the past decades, but in modern years it has been introduced in other manufacturing processes such as engraving, marking & machining of different materials due to inventions and progress, research & advancement in laser technology (Mehta et al., 2015).

### **2.3.1 Laser Engraving**

Laser engraving is a process of machining, where material is laser-graved. Laser engraving is the most effective approach in hard material machining and extracts layer by layer from the material. Many types of industrial lasers such as CO<sub>2</sub> laser and neodymium-doped yttrium Aluminium garnet (Nd : YAG) laser, fiber laser, semiconductor laser used in laser engraving processes (Patel et al., 2015). As previously conceived in 1990s by Indian scholar Babu, laser truing or dressing methods typically involve two steps, truing and dressing (Deng et al., 2014).

Laser engraving is the most useful method in the machining of hard materials which have a complex geometry compared to traditional methods. Hence, laser-based machining is commonly used in several industries such as mould fabrication and automotive, electronics and biomedical parts manufacturing. Owing to the geometrical constraints of the cutting tool, in some situations the geometry to be machined is not

achieved. Thermal machining techniques are thus the best approach when considering problems based on cutting tools. Electrical discharge machining (EDM) and laser beam machining (LBM) are among the few thermal machining processing in the metal processing industry, and they are frequently used to remove material in the contact region created by the vaporizing mechanism. Lasers are well known to be used in many industrial processes such as cutting, drilling, scribing and welding. Lasers have also been used in deep engraving applications over the last few years. Machining processes based on lasers are non-contact and use a high intensity beam as the cutting tool. Problems resulting from the cutting tool, the difficult geometry to machine and the hardness of the work piece material do not arise (Kasman, 2013).

#### **2.3.1.1 Principle of Laser Engraving**

Laser engraving process is a non-conventional process, contactless machining that is developing rapidly due to its capability to conduct high precision machining of geometrically complex on a wide variety of materials. With the benefit that there is no contact between a cutting tool and the work piece, the laser machining processes incrementally gain ground over traditional machining. This helps eliminate troubles such as wear or failure of cutting tools, and the need to periodically replace them, which increases the cost of production.

The fundamental working theory of the laser engraving process is that the laser beam is scanned over the workpiece. Next, the energy of the workpiece absorbs each laser pulse and heats the material, causing melting and finally vaporizing to a gas. This transformation phase from solid to vapour is called ablation. As even the evaporated